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Fatigue and Human Errors Analysis in Petrochemical and Oil and Gas Plant's Operation

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Abstract

Human Errors were attributed as one of the main causes of many industrial incidents and accidents in work place particularly in petrochemical, oil and gas plant's operation. One of the main contributors of human errors is fatigue, and fatigue occurred either due to insufficient sleep or disruptions in normal sleep cycle. Ultimately, the shift workers has high tendency to experiences fatigue due to shift rotation. Petrochemical, oil and gas plant adopted shift work schedule to ensure the continuity and to optimize the utilization of workforce. It is critical to analyse the relationship between fatigue and human errors to prevent accident/incident at workplace. A combination of quantitative and qualitative research was conducted using questionnaires for collecting primary data and a survey of literature related to fatigue and human errors for collecting the secondary data. The study was carried out to investigate the possible types of human errors and their causes that lead to incident/accident in petrochemical, oil and gas plant's operation and to evaluate the relationship between fatigue and human errors. Sample was taken from shift worker of operation team that consist of field operators, DCS operators and shift controllers. The study results demonstrated that there is a clear link between fatigue and human errors, human errors prevention done by preventing the fatigue. There are four types of human errors were investigated (lapses, slips, mistakes, and procedure violation). Fatigue can be prevented by modifying the working hours, reducing working hours, improving the working environments (lighting, display, noise, colour similarity, appearance similarity), simplifying the tasks, proper ratio between manpower and workload. The responsibility to manage fatigue should be taken by both employers and employees.

Keywords

Human Error; Fatigue; Shift Work; Petrochemical, Oil and Gas Plants

1. Introduction

Human Errors were attributed as one of the main causes of many industrial incidents and accidents at workplace (Ness, 2015; Jahangiri, 2015; Konstandinidou et al., 2006; Besnard and Hollnagel, 2014; Bridges & Tew, 2010; Taylor, 2013). Yeow et al. (2014) stated that 90% accidents that occurred in workplace are due to human errors, while Bridges & Tew (2010) argued that human errors caused 99% of accidental losses. The impact of those accidents are really huge. For example, The Formosa Plastics Corp. incident in 2004 killed five workers and seriously injured two others due to the operator overrode an interlock that led to a release of hot pressurized VCM, Bhopal incident (1984) kill more than two

thousand people, Piper Alpha incident (1988) caused more than 167 killed, Chernobyl incident (1986), Texaco Refinery incident in 1994, Three Mile Island, all are attributed to human errors. Fatigue is one of the frequent contributor of human errors, a feeling of tiredness, weariness or lack of energy (Lerman et al., 2012). Yeow et al. (2014) research found that a total of 48.8% of human errors caused by fatigue, stress, repetition, and work environments, ultimately fatigue is an unsafe condition in workplace (Lerman et al., 2012). Further Lerman et al. (2012) stated that fatigue occurred either due to insufficient sleep or disruptions in normal sleep cycle. Consequently, fatigue can be the result of shift rotation (Salma and Kameswara, 2012).

Shift work method is adopted in petrochemical, oil and gas companies' operation to ensure the continuity of operation and to optimize the utilization of workforce. Ultimately, shift workers tend to experiences fatigue, especially working at night shift worker difficult to get enough sleep. The combination of lack of sleep and conducting the job at the body's low point caused sleepiness and fatigue (Salma and Kameswara, 2012). That could be the reason why the accident at Three Mile Island, Chernobyl and Bhopal tragedy occurred in night shifts. Alert workers are paramount to safe and productive operations. In reality, every worker experiences fatigue with difference level time to time. Hence, unmanaged fatigue is a critical issue for the company since it is unsafe condition that affect the plant's operability, safety, health, and productivity. Motivated by these facts and looking at the cause and impact of those accidents, inspired by the limited study of human errors related to fatigue in petrochemical, oil and gas industries, and enlightened by the perspective that fatigue can be managed (Lerman et al. 2012), the researchers believed that a study need to be conducted to investigate the relationship between fatigue and human errors and find out the mitigation on how to manage the fatigue in workplace effectively. The study was carried out on May-June 2017 to the operation team of petrochemical, oil and gas plants.

The research objectives are to investigate the possible types of human errors and their causes that lead to incident/accident in petrochemical, oil and gas plant's operation, and to evaluate the relationship between the fatigue and human errors. The authors believed that the research outcome will provide the benefits to the individual, organization as well as society. Individual (employee and leaders) will recognize the possible human errors and how to minimize it in workplace, and can adopt the suggested strategy or techniques. While organizations can utilize it as an option for improving their existing system in order to shape an effective human errors prevention and mitigation systems. By doing so, it can improve their competitiveness in both national and international markets. In addition to that the companies can leverage their performance in their specific business area, since companies' achievement is depended on their employee's achievement. Moreover, academically it will enrich the current perspectives or notions on human errors prevention, risk control and mitigation, particularly in petrochemical, oil and gas plant's operation.

2. Materials and Methods

This research adopts descriptive researches that evaluate the relationships between a numbers of variables. A combination of quantitative and qualitative approaches has been used to collect and analyse data. A questionnaire survey from the operation team members has been done to collect the primary data. In this study the author adopt the fatigue analysis theory as the base for analyzing human error. In fatigue concept, the author use the Wilson (2015) perspectives stated that five factors that can lead to a fatigue state. They are: 1) circadian factors; 2) time since awakening; 3) quantity of sleep; 4) quality of sleep; and 5) sleep disorders. These five factors are the measure variables. While the dependent variables is the human errors, the human error will be measured using the variables: 1) Lapses, 2) Slips, 3) Mistakes, and 4) Procedure violations.

The study will start from the assumption that fatigue will lead to human errors, and human errors can be prevented and minimized by recognizing the possibility of human errors in plant's operation and their

causes, and then develop an effective design to prevent human errors in workplace. Figure 1 shows the conceptual framework to carry out the problem.

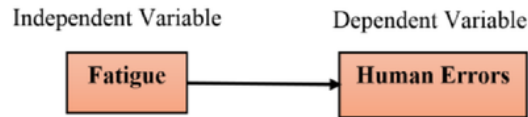


Figure 1. Framework

The primary data will be collected through survey or questionnaire to operation team that consists of operators, DCS / panel operators and shift controllers from petrochemical, oil and gas industries plants. The plant of petrochemical, oil and gas operated 24 hours, ultimately they adopted the shift work system. From the experiences of the author, he found that typical of a petrochemical, oil and gas plant consist of 10 personnel (1 Shift Controller/Shift Supervisor, 4 DCS operator, 5 Field Operator. A total of 37 personnel involve in the survey and provide the feedback.

The data was analysed and validated using statistical analysis to check the representativeness, accuracy, and precision. To increase the validity of the data, the participants taken will be selected from those who have experiences minimum two years in plant's operation.

3. Results and Discussion

The age of the respondents in this research was divided into five categories, the age less than 25 years, 25-30 years, 31-35 years, 36-40 years, and more than 40 years. The survey results displayed that none of respondents have the age meeting the first two categories. Majority of the respondents ages were more than 40 years (54%), there are 38% respondents were in the third categories 36-40 years, and only 8% of respondents were in second categories 31-35 years. The working experiences of the respondents in this research was divided into five categories including less than 5 years, 6-10 years, 10-15 years, 16-20 years, and more than 20 years. The survey results displayed that none of respondents has the working experiences that meeting the first two categories. There are 13 % respondents that have working experiences 10-15 years, 38 respondents have working experiences 16-20 years and 49 % have more than 20 years working experiences. The detail results listed in the Table 1.

Table1. Demographic of Respondents (Source: Survey Results by Researcher)

AGE (YEARS)	%	WORKING PERIOD	%
31-35	8.1	10-15	13.5
36-40	37.8	16-20	48.6
>40	54.1	>20	37.8
FIELD OF BUSINESS	%	QUALIFICATION	%
Petrochemical	83.8	High School	45.9
Oil	8.1	Diploma	32.4
Gas	8.1	Bachelor Degree & Above	21.6
JOB EXPERIENCES	%		
Field Operator	10.8		
DCS Operator	2.7		
Both DCS & Field Operator	64.9		
Shift Controller/Supervisor	21.6		

The respondents in this study have experiences working in three difference field of businesses. Accordingly, the respondents were divided into three distinct group including, Petrochemical Company, Gas Company and Oil Company. The majority of respondent (84%) coming from petrochemical companies, while in both gas and oil accounted 8% respectively. Jobs Experiences of the respondents in operation team are various. Field Operator accounted for 11%; DCS Operator has accounted only 3%; a total of 65% accounted for both Field and DCS Operator and Shift Controller/Shift Supervisor accounted 21% from the total of the sample. The respondents' qualifications in this study come from various educational background. Most of them (45.9%) having High School/Secondary School, 32.4% have Diploma educational background, and the rest (21.6%) were having Bachelor Degree or above educational background.

In this research, independent variables is fatigue and dependent variable is the human errors. The data obtained from the respondents before further analysis were tested their reliability and validity. The reliability was tested using Cronbach's Alpha and the validity was tested using KMO and Bartlett's Test. Both reliability and validity tests result showed that data were valid. Fatigue accounted 0.960 Cronbach's Alpha and 0.634 KMO and Bartlett's of Sampling adequacy. While, human error variable accounted 0.903 Cronbach's Alpha and 0.657 KMO measure of sampling adequacy.

To analyze the fatigue, the respondents were given a questionnaire set that contain the questions asking their agreement on set of expression based on their experiences working in shift in relation to the fatigue. Five dimensions were used as measure variables with a total of 27 indicators. The five dimensions are: 1) circadian factors to see the effect of circadian rhythm changes to employees' fatigue; 2) time since awakening to evaluate the awareness of employee on number of their awakening time and how it affect their fatigue; 3) quantity of sleep, to evaluate the number of normal sleeping hours to keep body fits for the employee, the effect of having less sleeping hour compared to normal sleeping hours on fatigue; 4) quality of sleep, to investigate the effect of shift work schedule on the quality of sleep and fatigue; and 5) sleep disorders, to understand the shift worker possibility to have the slip disorder.

Research data demonstrated that most of employee agreed that circadian factors caused fatigue and can lead to human error (47.30 % agree and 9.46 % strongly agree), neutral accounted 17.57 % and respondents who disagree accounted 17.57% and strongly disagree accounted only 8.11%. Time Since Awakening dimensions displayed that most employees agree that having more time awakening will caused fatigue, reduce their memory and concentration and lead to human error (48,11% agree and 12.43% strongly agree), while 16.76% were neutral, 14.05% were disagree, and only 8.65% were strongly disagree. On the third dimensions of fatigue, quantity of sleep, the research results showed that majority of the respondents agree (50.81% agree and 25.41% strongly agree) that they know their normal sleeping hours, overtime, prolonged workload and work stress reduce their sleeping time, less sleeping hours than normal hours (less than 6 hours) reduce the alertness, decrease the performance, caused fatigue. Neutral account 9.73 %, and both disagree and strongly disagree accounted 7.03 % respectively. Whilst the forth dimensions, Quality of Sleep, the study results exhibit that more than half or respondent supported that rapid changing shift, after night shift, extended work hours more than 12 hours, affect their quality of sleep (48.11% agree, 19.46% strongly agree), 14.59% neutral, 9.19% were disagree and 8.65 % were strongly disagree. And the last dimensions, sleep disorder study results informed that badly cough, going to bathroom frequently, mental depression, frequent awakening in sleeping period caused sleep disorder that lead to fatigue and human errors (48.85% agree and 11.71 strongly agree), 18.47 % neutral, 15.77 % disagree and 7.21 strongly disagree. Detail distribution of dimensions of fatigue variables displayed at table Data gained from the survey results analyzed and put in tabulation as displayed at Table 2.

Table 2. Demographic of Respondents (Source: Survey Results by Researcher)

NO	Dimension	SD		D		N		A		SA	
		Mean	%	Mean	%	Mean	%	Mean	%	Mean	%
1	Circadian Factors	3.00	8.11	6.50	17.57	6.50	17.57	17.50	47.30	3.50	9.46
2	Time Since Awakening	3.20	8.65	5.20	14.05	6.20	16.76	17.80	48.11	4.60	12.43
3	Quantity of Sleep	2.60	7.03	2.60	7.03	3.60	9.73	18.80	50.81	9.40	25.41
4	Quality of Sleep	3.20	8.65	3.40	9.19	5.40	14.59	17.80	48.11	7.20	19.46
5	Sleep Disorder	2.67	7.21	5.83	15.77	6.83	18.47	17.33	46.85	4.33	11.71

Note: SD (Strongly Disagree), D (Disagree), N (Neutral), A (Agree), SA (Strongly Agree). Source: SPSS Analysis Results by Researcher

In order to see the mean comparison between dimensions of independent variable (system approach) the bar graphic was created as displayed at Figure 2.

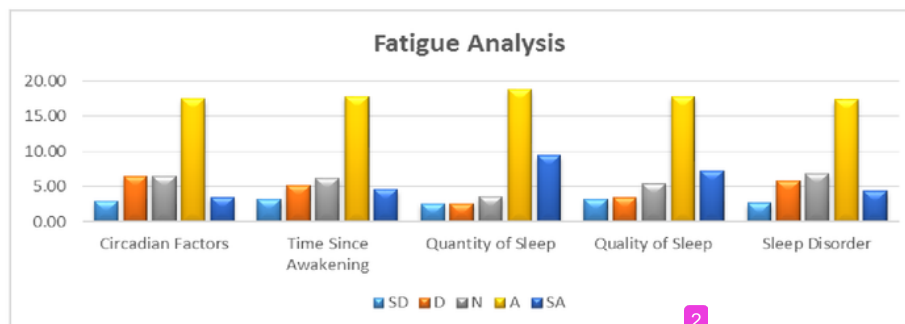


Figure 2. Fatigue Analysis. Source: SPSS Analysis Results by Researcher. Note: SD (Strongly Disagree), D (Disagree), N (Neutral), A (Agree), SA (Strongly Agree).

Similar to fatigue variable, to analyze the human errors variable, the respondents were given a questionnaire set that contain the questions asking their agreement on set of expression based on their experiences working in shift in relation to the human errors. The human error will be measured using five dimensions such as: 1) Lapses (forgetting to do something), 2) Slips ('Whoops', not doing what worker's meant to do), 3) Mistakes (decision making failure), and 4) Procedure violations (an intentionally inappropriate action done by the person), and a total of 17 indicators. Detail of data analysis of dependent variables will be displayed as follows. Lapses dimension was evaluated to know the impact of distraction and interruption in working environments, jobs characteristic, fatigue, to the memory and concentration of worker that lead to human error (lapses). The second dimensions, Slips was investigated to check the effect of number of alarms in DCS at a time, color similarity for alarms, poor display, similar appearance on the worker concentration that lead to human errors, it relation to the fatigue. While the third dimension of human error, mistakes were examined the influence of work load, time pressure, task complexity, and similarity in sound and tone of different alarms to the possibility of worker mistakes. Finally the last dimensions, procedure violation, was inspected to see the relation between too many task with too little number of worker, work stress, peer pressure, not having right tools/equipment, and wanting to take the easy option in doing the job.

The results of the data analysis displayed that most of employee agree that lapses can be occurred when the employee has interruption in working environments, jobs characteristic, fatigue (55.68 % agree and 11.35 strongly agree), 14.05% neutral, 11.35% disagree and 7.57% strongly agree. Slips dimensions demonstrated that majority of the respondents agree (54.73% agree and 22.97 % strongly agree) that slips occurred when too many alarms in DCS sounding at a time, alarms' color similarity, poor display, similar

appearance. Neutral accounted 8.78%, disagree accounted 7.43% and strongly agree 6.08%. Whilst, the mistakes dimensions study results showed that more than half of respondents agree that mistakes can be happened when worker has high work load, and time pressure (54.05% agree and 22.30% strongly agree), 9.46% were neutral, 8.78% disagree, and strongly agree accounted 5.41%. Whereas the last dimension results of human errors, procedure violations depicted that majority of respondents (45.27% agree and 28.38 % strongly agree) that too many tasks with too little number of worker, work stress, peer pressure, not having right tool/equipment, and wanting to take easy option in doing the job can trigger the employee to violate the procedures. The remaining are neutral (9.46%), disagree (3.75%) and strongly disagree (6.76 %). The detail distribution of dimensions of human errors variables can be seen at Table 3.

Table 3. Distribution of Mean of Human Error Variables (Source: Survey Results by Researcher)

NO	Dimension	SD		D		N		A		SA	
		Mean	%	Mean	%	Mean	%	Mean	%	Mean	%
1	Lapses	2.80	7.57	4.20	11.35	5.20	14.05	20.60	55.68	4.20	11.35
2	Slips	2.25	6.08	2.75	7.43	3.25	8.78	20.25	54.73	8.50	22.97
3	Mistakes	2.00	5.41	3.25	8.78	3.50	9.46	20.00	54.05	8.25	22.30
4	Procedure Violations	2.50	6.76	3.75	10.14	3.50	9.46	16.75	45.27	10.50	28.38

Note: SD (Strongly Disagree), D (Disagree), N (Neutral), A (Agree), SA (Strongly Agree). Source: SPSS Analysis Results by Researcher.

In order to see the mean comparison between dimensions of independent variable (system approach) the bar graphic was created as displayed at Figure 3.

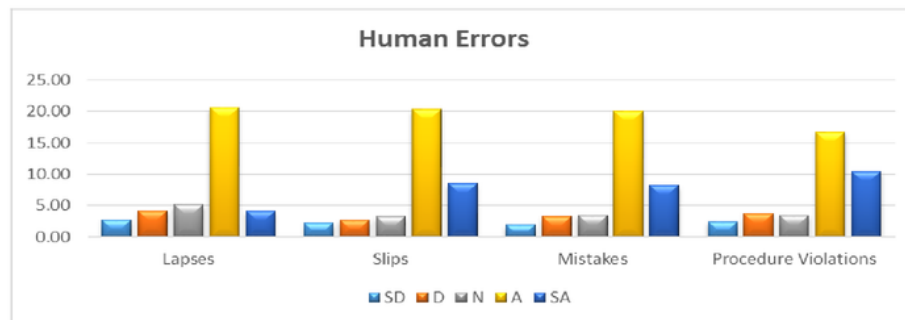


Figure 3. Fatigue Analysis. Source: SPSS Analysis Results. Note: SD (Strongly Disagree), D (Disagree), N (Neutral), A (Agree), SA (Strongly Agree) by Researcher

Shift workers who operate the petrochemical, oil and gas plants have high tendency to experience fatigue. Overall study demonstrated that the combination of circadian rhythm changes, long working hours, less sleep hours, low sleeping quality and sleeping disorders are responsible for high level of sleepiness and fatigue during the work periods. They affect the endurance and body fitness, and decrease the concentration, body feel uncomfortable, irritable, anger depression, and mental stress. Psychological problem can be occurred because of sleeplessness and fatigue (Salma and Kameswara, 2012). This condition support errors or accident (Costa, 2016).

Fatigue will dull workers' memory, lowering the concentration that lead to forgetting to do something, while executing the job it can lead to human error (lapses). Ultimately, the shiftwork will bring negative impacts by increasing the risk for lowered performance on the job due to fatigue and sleepiness. The irregularities in the circadian rhythm and the natural waking and sleeping, and inability to adapt with new conditions decrease the cognitive performance particularly in the night shift (Kazemi at al., 2016).

Eventually, fatigue workers endanger themselves or others while commuting from work to home and vice versa (Caruso, 2014, Costa, 2016). Researcher has witnessed a traffic accident while commuting from work to home in 2016 that resulted to five of his colleagues injured. In addition, a fatal accident happened in 2016 in researcher previous company due to prolonged working time or over time, the employee worked from 07:30 hours till 03:00 hours (19.5 hours) in next day, while commuting from workplace to home at early morning on the next day, the vehicle that he drove hit two pedestrians, caused one fatality and one seriously injured. Fatigue and poor shift schedule also depicted as a major contributor for major accidents (Costa, 2016). This is confirmed the finding that prolonged working time more than 12 hours caused fatigue and decrease the concentration of the employee and may lead to human errors.

In addition to that, slips can be occurred when the concentration of worker disturbed due to too many alarms sounding at one time, similarity in coloring of alarms and appearance in buttons or switches, and poor display. Further, high work load, time pressure, task complexity, and similarity in sound and tone of different alarms can lead to miss interpretation that will lead to mistakes. Moreover, procedure violation can be happened when too many task with too little number of worker, work stress, peer pressure, not having right tools/equipment, and wanting to take the easy option in doing the job. Consequently, employers should provide safe work schedules that allow employee to have an adequate amount of time to sleep, rest and recover. The modification of working time can decrease the workload and stress, for example, to provide enough time for preparing the work permit, so the day shift time can start earlier one hour, and maintenance regular shift technician can start working time late one hour than the usual, so there is larger time span (two hours) to prepare work permit. This time modification will lessen the stress level for shift controller in day time that ultimately will reduce the fatigue.

Additionally, in respects to the finding, another preventing measures can be done by improving the working environments (less disturbance/good lighting), alarms managements (reducing the alarms amount at the time), reviewing the DCS display, reducing color similarity for alarm and buttons or switches appearances, simplify the tasks, proper ration between man power and work load/tasks. Kazeni et al. (2016) suggested to provide employee to take naps during night shifts, in my views this action will be difficult to control, in my experiences working in shift I have seen people could not take naps in short time during night shifts. Another suggestions by reducing working hours so employee will have enough time for rest, hence, this will increase cost, particularly for petrochemical and oil and gas companies that operating 24 hours. Putting the responsibility to manage the fatigue to employers alone is not fair, thus, the employees also need to put himself a duty to utilize their off -working hours wisely to have sufficient sleep and recovery in order to be able to do their task safely and appropriately.

The theoretical implication of the study is that it enriches, validates, and integrates the current literatures related to fatigue and it links with human errors and accident causations theory. It offers a clear evidence from the petrochemical, oil and gas plants' operation that fatigue will lead to human errors in workplace and human errors can be **revented by managing the fatigue**. This leads researcher to believe that company needs to involve **fatigue and human error** analysis in its **safety and health** policy to prevent the accident at workplace, to ensure the continuity of operation and to optimize the utilization of workforce to meet the expected operability, safety, health, and productivity. Next, findings reconfirm the notions that fatigue can be managed (Lerman et al., 2012). It supports the perspective that shift rotation cause fatigue (Salma and Kameswara, 2012) and fatigue can lead human errors (Yeow et al., 2014).

The responsibility to manage fatigue should be taken by both employers and employees, employers responsible to provide a safe and proper working schedule to allow employee has an adequate rest and recovery. While, employees should take a responsibility to utilize their off-working time wisely to ensure gain enough rest and recovery in order to be able to do their task safely and appropriately. It may be that the findings were influenced by the some facets including researcher personal experiences, **pectives** and educational. It possible that participants did not share the whole experiences during **filling the**

questionnaires. The questionnaires were written in English, hence the researcher and participants non-British citizens it could be some limitation in interpreting the statements in questionnaires. The researcher cannot be sure that the participant's interpretation of the variables is the same within the study or across the different plants. Future research can consider and reduce or eliminate those limitations, analyze the fatigues in relations to the geographic, climate at which the plants situated.

4. Conclusion

All in all, the research results displayed very clear links between fatigue and human errors for shift worker in petrochemical, oil and gas plant's operation. Prevention of human errors can be done by reducing fatigue. Fatigue can be reduced by modifying the working hours, reducing working hours, improving the working environments (lighting, display, noise, color similarity, appearance similarity), simplifying the tasks, proper ratio between manpower and workload (tasks). The practical implication to organizations, the findings suggest that company needs to provide training or workshop about fatigue and human errors preventions to shift workers on how effectively to maintain the fitness of shift worker, modify the existing working environments, job characteristics, having a proper manpower planning to ensure proper job and worker ratio. On individual level, the findings provide insights to shift workers, health and safety professional, students, the impact of shift rotation, circadian factors, time since awaking, sleep quality, sleep quantity, and sleep disorder to fatigue and human errors.

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Biographies

Include author bio(s) of 200 words or less.

Made Mardiana is a graduate in Master of Industrial Engineering from Bina Nusantara University. He has been working in oil and gas industries for more than 12 years. Currently, he is trainer in one of oil and gas industry in Middle East.

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